Measurement of Low Transverse Momentum Direct Photons Via External Conversions in Au+Au Collisions at sqrt(s) = 200 GeV with the PHENIX Detector at RHIC

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PHENIX (Pioneering High Energy Nuclear Interaction eXperiment) is one of the large experiments taking place at the Relativistic Heavy Ion Collider (RHIC) located at Brookhaven National Lab (BNL) on Long Island, New York.

PHENIX has two major programs, a heavy ion program and a spin program. The former seeks to create and characterize a new state of hot, dense matter (the Quark Gluon Plasma, or QGP), where quarks and gluons are the relevant degrees of freedom in the system. The latter focuses on probing the gluon contribution to the spin of the proton by colliding polarized protons and measuring a spin asymmetry.

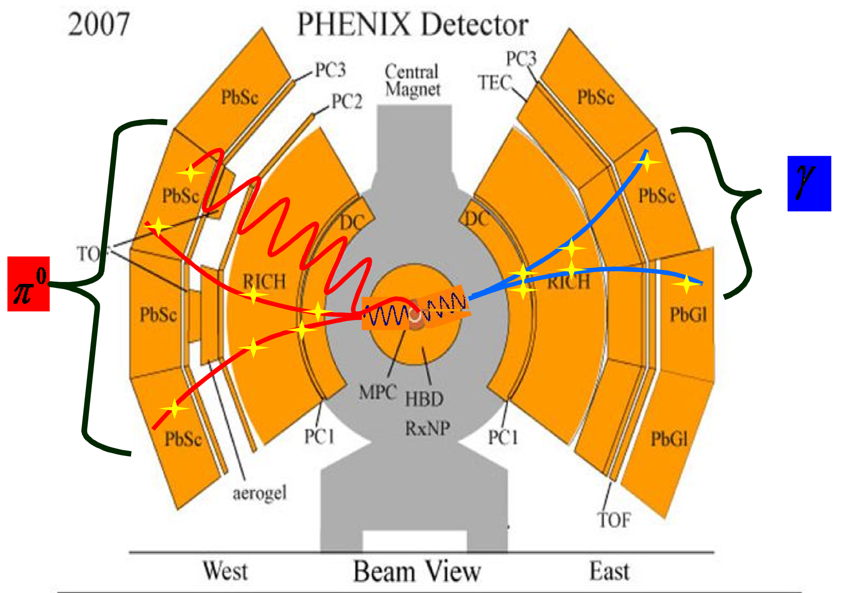

Figure 1: The PHENIX detector, 2007 configuration. The blue lines indicate e+ and e- tracks from a photon converting in the HBD. The red lines indicate a pi0 that decayed into photons, one of which converts in the HBD

Motivation for Studying Direct Photons

Photons are an important probe of the produced medium because they have a very weak interaction with the medium. Thus they allow us to get information about all stages of the collision.

Direct photons (photons that do not come from decay processes) have been previously measured at PHENIX, [1],[2].

In this poster, we focus on measuring direct photons at low transverse momentum. Measuring the low momentum photons is difficult at PHENIX because of the high multiplicity of low momentum particles in Au+Au collisions. This is why it can be advantageous to measure photons through conversion processes, where the photon converts in to an e^+/e^- pair, which PHENIX is well equipped to measure in a large momentum range.

PHENIX has previously measured low momentum photons by studying virtual photons through internal conversion processes [2].

This poster presents a complementary analysis, where we aim to measure the same momentum range, but of real, not virtual, photons. These real photons are measured through external conversions of the photon in the HBD backplane, see fig. 1. This measurement will strengthen the findings detailed in ref.[2].

Analysis: The Double Ratio

An excess of photons over hadronic sources can be measured through a double ratio. We also employ a tagging method where converted photons can be tagged as coming from a π^0 decay by measuring the second photon in the electromagnetic calorimeter, see fig. 1. This allows major sources of systematic error to cancel when making a ratio.

$$\frac{\gamma^{incl}(p_T)}{\gamma^{hadr}(p_T)} = \frac{\left[\varepsilon_\gamma(p_T)\cdot\left(\frac{N_\gamma^{incl}(p_T)}{N_\gamma^{\pi^0 tag}(p_T)}\right)\right]_{Data}}{\left[\left(\frac{N_\gamma^{hadr}(p_T)}{fN_\gamma^{\pi^0}(p_T)}\right)\right]_{Sim}}$$

The numerator of this double ratio is the ratio between the inclusive photon yield (the converted photons) and the yield of inclusive photons that have been tagged as coming from a π^0 decay. Notice that because of the tagging method, the pair efficiency and the pair acceptance cancels in the ratio.

DATA

$$N_\gamma^{incl}(p_T) = c\varepsilon_{pair} a_{pair} \gamma^{incl}(p_T)$$

$$N_\gamma^{\pi^0 tag}(p_T) = c\varepsilon_{pair} a_{pair} \varepsilon_\gamma f \gamma^{\pi^0}(p_T)$$

The denominator of the double ratio takes into account other hadronic contributions to the photon yield. This is measured through full Monte Carlo Simulations.

SIMULATION

$$N_\gamma^{hadr}(p_T) = a_{pair}\gamma^{hadr}(p_T)$$

$$N_\gamma^{\pi^0 tag}(p_T) = fN_\gamma^{\pi^0} = a_{pair} f \gamma^{\pi^0}(p_T)$$

Isolating External Conversions

The PHENIX tracking software assumes that all particle track originate at the event vertex. Of course this is not always true. This assumption for conversions gives an apparent opening angle and invariant mass to the pair, see fig. 2.

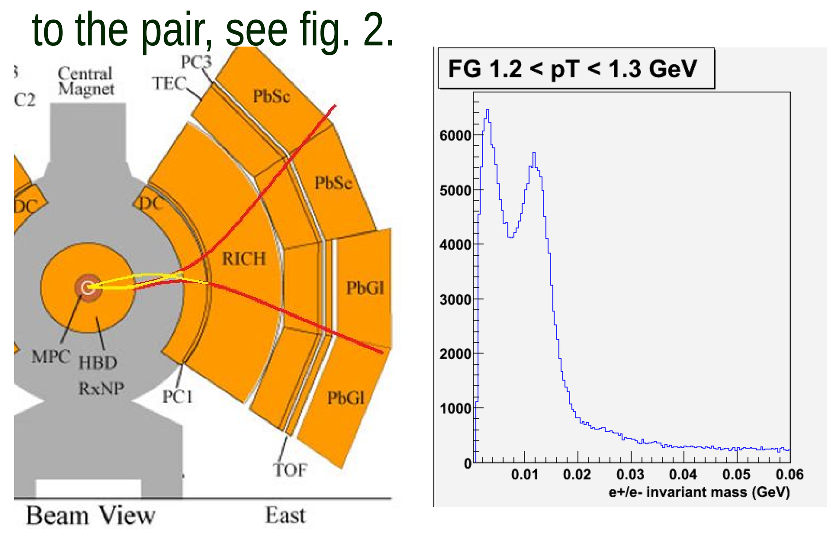

Figure 2: Left: The red lines represent the true track trajectories (track origin in the HBD shell), the yellow lines are the same tracks under normal PHENIX reconstruction.

Right: e^+/e^- invariant mass distribution. Visible is a Dalitz peak near zero and an HBD conversion peak at 12MeV.

ϕ_V

One of the tools we have in isolating photon conversions is ϕ_V, a measure of the angle between the opening plane of the pair and the magnetic field, see fig. 3. Daltiz pairs will open randomly.

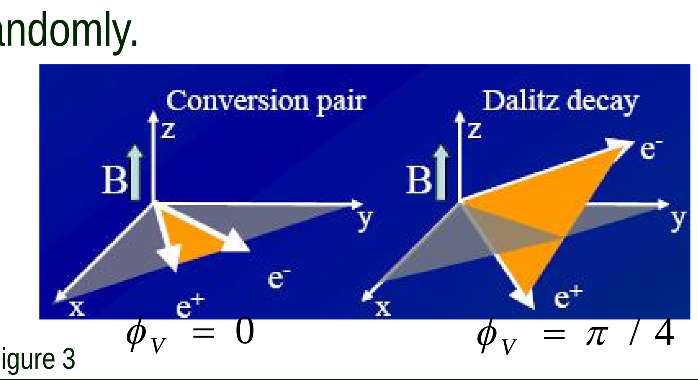

Figure 3

An Alternate Track Model (ATM)

In order to improve the photon conversion sample purity, we have developed an alternate track model. In this alternate tracking model, tracks are assumed to come from the HBD shell, rather than from the event vertex. Under this assumption, the conversions from the HBD are then properly reconstructed, where as everything else is misreconstructed.

This has the effect of shifting the invariant mass peak of the HBD conversions to zero mass, while moving all other pair masses to higher mass, allowing for cleaner separation.

This alternate track model is realized by studying full Monte Carlo simulations in which all the particles come out radially from 60cm. Then a mapping is found between the basic measured track variables φ_{DC}, θ, and α in normal PHENIX reconstruction (NPR) and the true track variables at the HBD shell, φ_{HBD}, θ_{HBD}, and p_T. Simple functions relate them. The application of this model can be seen in fig.5 for simulations and fig. 6 for data .

$$\varphi_{HBD} = \varphi_{DC} - (C_0 + C_1\cdot\alpha + C_2\cdot\alpha^2 + C_3\cdot\alpha^3)$$

$$\theta_{HBD} = \cos^{-1}(C_0 + C_1\cdot(zed - vertex_{BBC}))$$

$$p_{T,HBD} = m\cdot\frac{1}{\alpha} + b$$

where

$$m = C_{slope,0} + C_{slope,1}\cdot|zed| + C_{slope,2}\cdot|zed|^2$$

$$b = C_{offset,0} + C_{offset,1}\cdot|zed|$$

The performance of the ATM in HBD conversion simulations is shown in fig. 4. Here we compare the residuals between the PHENIX reconstructed (ATM) value and the true MC value. The error bars represent the RMS of the residual distribution. It can be seen that the ATM p_T is corrected compared to NPR. The ATM φ reconstruction is much more accurate than the NPR. The ATM θ is not significantly better.

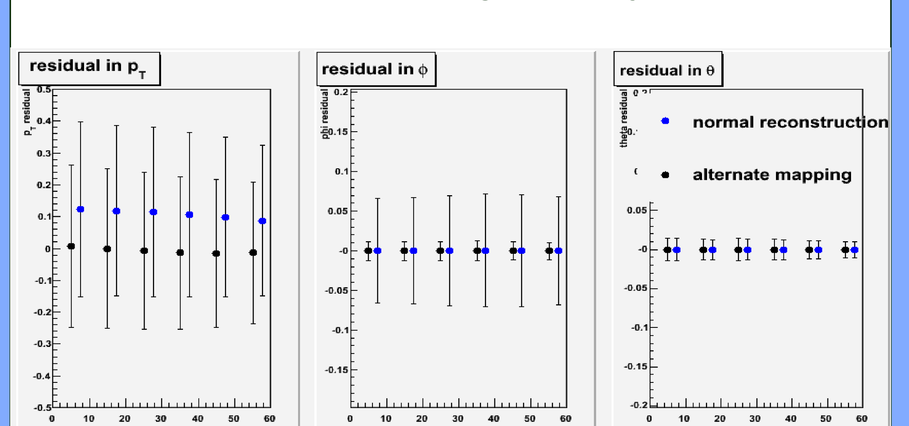

Figure 4

Simulations

The effect of the alternate track model can be seen in fig. 5 for simulated data. On the left, conversion pairs from various material sources is shown. Dalitz pairs are on the right.

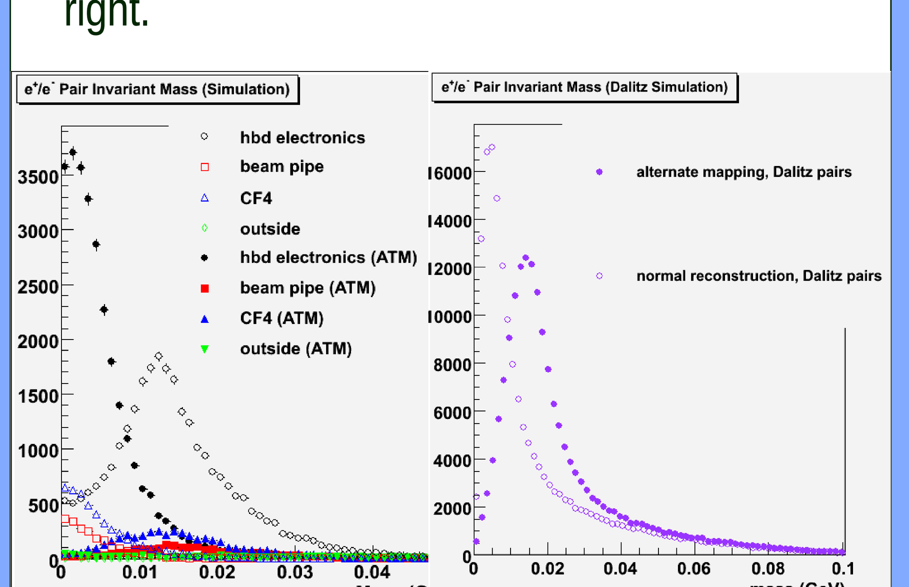

Figure 5

Alternate Track Model on Real Data

In fig. 6 we compare the invariant mass calculated with the ATM and with normal reconstruction. The desired effect is seen. The Dalitz and HBD conversion peaks more or less trade places. To illustrate this, mass selection windows are chosen. The purple squares show the Dalitz region; the HBD conversion region in black triangles.

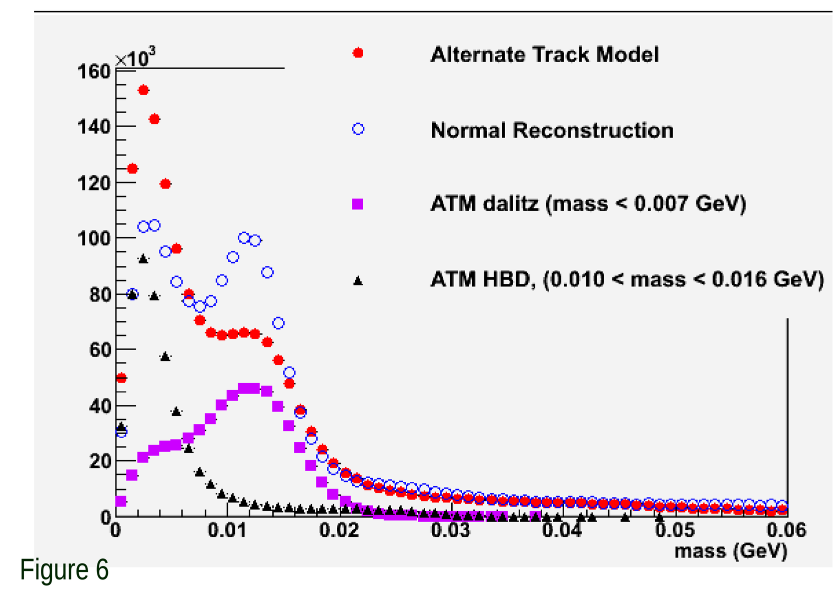

Figure 6

New Cuts

The alternate track model allows us to make new cuts. Under this method, we have both the normally reconstructed mass and the alternate track model mass. Cutting on this may be useful, see fig 7.

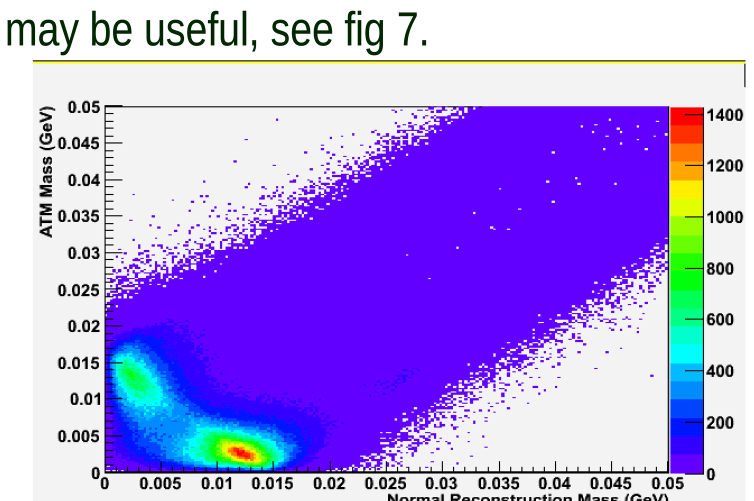

Figure 7: A 2D histogram of the normal y reconstructed invariant mass and the ATM invariant mass. A clear separation of the Dalitz and HBD conversion pairs can be seen.

In addition, we can cut on the separation between the tracks at the HBD using the ATM values, see fig. 8.

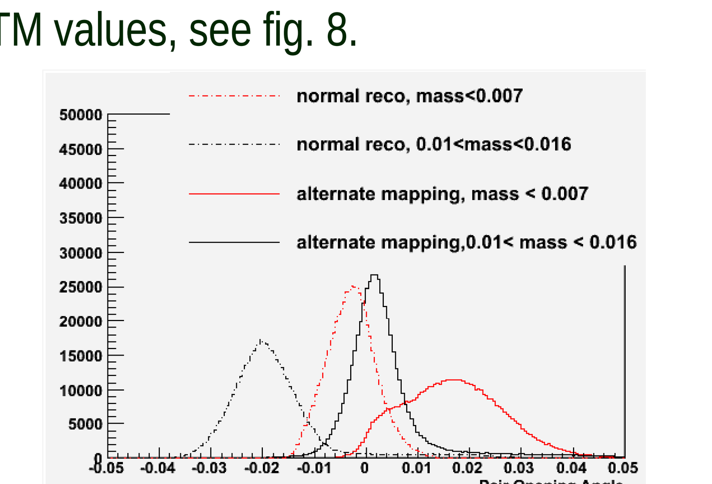

Figure 8: The opening angle of the e+/e- pair. The same mass selection windows in fig. 5 are used here. Daltiz in red, conversions in black.

Summary and Outlook

The cuts introduced above still need to be optimized to get the cleanest photon sample possible. Then the inclusive yield can be calculated, along with the π^0 tagged contribution. This is shown using a ϕ_V cut in fig. 9.

All of the corrections are also still underway. The result is expected by the end of the year.

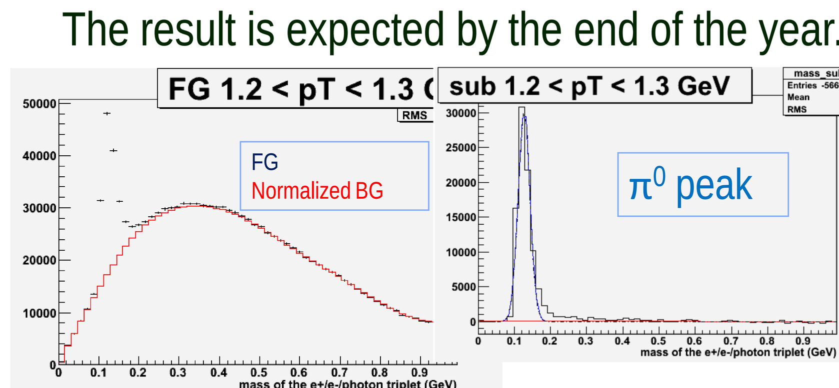

Figure 9: The left shows the FG (black) and BG (red) mass distributions for e+/e-/gamma combinations. The right is the background subtracted π^0 signal. The background is normalized using a mixed event technique.

References

[1] S.S. Adler et al., Phys.Rev.Lett.94:232301,2005

[2] A. Adare etal., Phys.Rev.Lett.104:132301,2010